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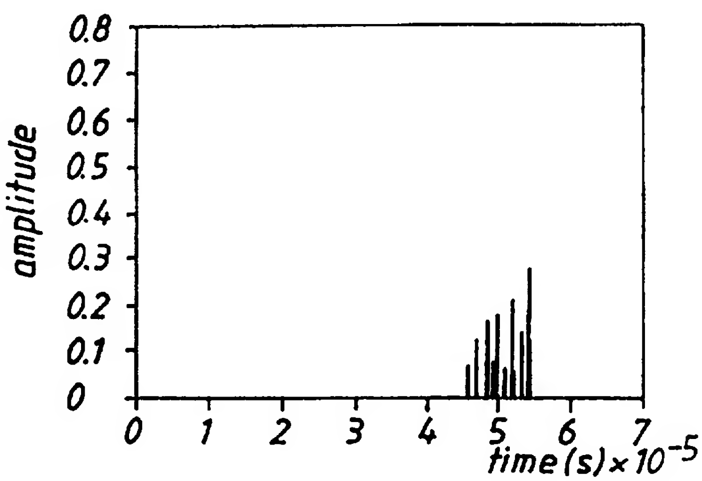
(57) Abstract

To ensure that the performance of an OFDM system is adequate, it is necessary to provide a guard space between symbols so that the effects of mutual interference between adjacent symbols is avoided. In a conventional OFDM system the length of this guard space must be equal to, or greater than, the maximum delay spread in the system. Bearing in mind that under some conditions the delay spread in a mobile system may be large, while under other conditions the delay spread may be low, the use of a fixed guard space corresponding to the longest delay spread, imposes an overhead on the transmission capacity of a communications channel. This conflict between channel traffic capacity and the need for long guard spaces between symbols can be overcome by using a variable length guard space, i.e. a guard space of variable duration. A receiver is able to instruct a transmitter to increase the duration of the guard space if the system performance is degraded.



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Improvements in or Relating to OFDM Systems

The present invention relates to OFDM (orthogonal frequency division multiplex) telecommunications systems, and methods of operating such systems, more particularly to the use of variable guard spaces in such systems.

In an OFDM system data is modulated onto a broadband signal comprising a large number of individual frequency carriers which form a frequency division multiplex. The bandwidths of the individual frequency channels, are small and arranged so that the maximum of the sinc(x), (sinc(x) = sin(x)/x), power spectrum, of one channel, corresponds with the first minimum in the sinc(x) power spectrum of the adjacent channels. In other words, the channel separation equals 1/(symbol length), for rectangular symbols. It is for this reason that adjacent channels are described as "orthogonal". OFDM systems normally use a FFT (fast fourier transform) process to demodulate the data signal from the transmitted signal. Convolution error coding and FFT may be employed at the modulator (transmitter) stage. In the receiver, complementary FFT processing is combined with Viterbi decoding, at the demodulator stage. This ensures that the overall bit error rate is very low. This particular variant of OFDM is known as COFDM (Coded Orthogonal Frequency Division Multiplex). In recent years, COFDM systems have been developed for a variety of broadcasting applications, e.g. for digital audio broadcasting and high definition TV. For convenience, in this specification the term OFDM is used to refer to both OFDM and COFDM.

The next generation of mobile communications systems may, with advantage, employ OFDM. However, in

mobile communications systems the distance between a receiver and transmitter is not constant and, in addition, the terrain between receiver and transmitter may vary. This results in signal dispersion in the frequency domain, or delay spread in the time domain, in a communications channel employing OFDM.

To ensure that the performance of an OFDM system is adequate, it is necessary to provide a guard space between symbols so that the effects of mutual interference between adjacent symbols is avoided. In a conventional OFDM system, the length of this guard space must be equal to, or greater than, the maximum delay spread in the system. Bearing in mind that under some conditions the delay spread in a mobile system may be large, while under other conditions the delay spread may be low, the use of a fixed guard space corresponding to the longest delay spread, imposes an overhead on the transmission capacity of a communications channel. Any compromise in the selection of the length of guard space will, in some circumstances, cause a loss of transmitted data.

It is an object of the present invention to minimise the overhead imposed on channel traffic capacity in an OFDM system by the use of a guard space between symbols, without degrading system performance.

The use of guard spaces in mobile telecommunications systems is well known. European Patent Application EP 0,295,227 describes a digital TDMA (time division multiple access) mobile telephone system in which time slot assignment is made in dependence on the propagation time between different mobile stations and a base station. Each time frame includes a guard space used to avoid overlap between transmissions to, or from, different mobile stations.

US Patent 5,371,548 discloses the use of guard spaces with OFDM systems.

European Patent Application EP 0,589,709 A2 discloses an OFDM system employing quadrature amplitude modulation, or modified phase shift keying, in which long guard times and/or wider channel spacings are employed.

US Patent 4,937,819 discloses a TDMA system in which ranging, with respect to time, is employed to reduce guard times between successive transmissions.

The present invention overcomes the conflict between channel traffic capacity and the need for long guard spaces between symbols by using a variable length guard space, i.e. a guard space of variable duration. A receiver is able to instruct a transmitter to increase the duration of the guard space if the system performance is degraded.

The use of variable duration guard spaces in OFDM systems is not disclosed in the prior art.

According to a first aspect of the present invention, there is provided an OFDM system comprising a receiver and a transmitter, said transmitter being adapted to transmit data in OFDM symbol bursts in which, in the time domain, a portion of a symbol burst is repeated within said symbol burst as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised in that said repeated portion of a symbol burst has a duration which is variable and which is adjusted, during system operation, to a minimum duration necessary to prevent data loss caused by delay spread.

Preferably said receiver is adapted to vary said time window to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

The portion of said symbol burst which is repeated may be copied from a leading edge of said symbol burst.

Said repeated portion of said symbol burst may be repeated at a trailing edge of said symbol burst.

Said receiver may be adapted to transmit a signal to said transmitter indicative of a level of delay spread in a received signal, and said transmitter is adapted to adjust said guard space duration to a minimum value necessary to prevent data loss caused by delay spread.

Preferably said receiver is adapted to detect a transmitted signal when said time window is incorrectly adjusted.

Said OFDM system may be adapted to operate as a mobile telecommunications system.

According to a second aspect of the present invention there is provided a receiver, for use with an OFDM system including a transmitter adapted to transmit data in OFDM symbol bursts, in which, in the time domain, a portion of a symbol burst is repeated within said symbol burst as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised in that said repeated portion of a symbol burst has a duration which is variable and said receiver is adapted to vary said time window to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss

caused by delay spread.

Preferably said receiver includes performance measuring means for measuring received signal quality and reception window adjusting means for adjusting said time window duration in response to a signal from said performance measuring means.

Preferably said receiver is adapted to transmit a signal to said transmitter indicative of a level of delay spread in a received signal, and said transmitter is adapted to adjust said guard space duration to a minimum value necessary to prevent data loss caused by delay spread.

Said receiver may be adapted to detect a transmitted signal when said time window is incorrectly adjusted.

According to a third aspect of the present invention there is provided a method of operating an OFDM system comprising a receiver and a transmitter, by transmitting data as a series of OFDM symbol bursts, each symbol burst, in the time domain, having a portion thereof repeated therein as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised by the repeated portion of a symbol burst having a variable duration, and adjusting said variable duration to produce a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

Preferably said receiver time window is adjusted to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

The repeated portion of said symbol burst may be copied from a leading edge thereof.

The repeated portion of said symbol burst may be repeated at a trailing edge of said symbol burst.

Said receiver may measure received signal quality and may adjust said time window duration so that said received signal quality exceeds a predetermined threshold.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a typical impulse response for hilly rural terrain.

Figure 2 shows a typical impulse response for urban terrain.

Figure 3 shows a typical impulse response for the interior of a building.

Figure 4 shows a typical impulse response for a micro cell in a cellular digital mobile telephone system.

Figure 5 is a diagrammatic illustration of an OFDM transmission burst.

Referring to Figure 1 to 4, there is shown the effect of terrain on delay spread, in an OFDM system. As can be seen from the drawings delay spread can vary from 0.2μs to 50μs. If a guard space is to be used which will avoid inter-symbol interference, caused by delay spread, in all of the different environments for

which impulse responses are illustrated in Figures 1 to 4, it will need to be equal, or greater than, 50μs. In the case where delay spread is equal to 0.2μs this imposes an unnecessary loss of channel capacity. It should be noted that the delay spread in the time domain transforms to frequency dispersion in the frequency domain. Whether the effect is viewed as a frequency dispersion, or a time dispersion, the effect is the same, i.e. loss of channel capacity.

The use of a guard space in an OFDM system, to overcome the effect of delay spread, is illustrated in Figure 5. The guard space takes the form of a cyclic repetition of the first part of an OFDM burst, i.e. the beginning of the OFDM burst is copied and repeated at the end of the burst. The OFDM symbol duration is denoted by T_s and the duration of the guard space is denoted by T_g. An OFDM receiver has a time window in which it can receive an OFDM symbol. The minimum duration of this time window is equal to T_s. The receiver can, therefore, only see that part of the signal which is not destroyed by delay spread in the communications channel. A receiver must, therefore, have a time window which corresponds to $T_s + T_g$. The loss of performance imposed by the use of a guard space T_g is Δ, where: $\Delta = 10\log(T_g/T_s)$dB. By using a variable guard space, as opposed to a fixed guard space having a duration corresponding to the maximum needed to overcome the effects of delay spread, the loss of system performance is reduced to the minimum extent necessary to avoid loss of data. In order to take account of known delay spread in different environments, T_g must be capable of being varied from 0.2μs to 50μs.

The concept of the present invention, namely the use of a variable guard space can be implemented in an OFDM system as explained below. The guard space is

inserted into the transmitted data stream after modulation and before multiplexing by the transmitter. In the multiplexed OFDM signal, the guard space is transformed into an increase in the carrier spacing present in the OFDM burst, in the frequency domain. At the receiver, the guard space is regenerated when the OFDM burst is demultiplexed by FFT (fast fourier transform) processing. The receiver can detect the OFDM burst even if its time window is incorrectly set, and can adjust its time window to the correct value for proper reception of subsequent OFDM bursts.

When the system is adapted for the two way transmission of data, i.e. when the receiver has a transmission capability, the receiver may measure the delay spread present in a received signal and transmit a control signal to the transmitter which causes the transmitter to adjust the duration of T_g to the minimum value needed to overcome loss of data through delay spread. In this way, the system uses the minimum guard space necessary to overcome the effects of delay spread, thereby maximising the channel traffic capacity without signal degradation in the receiver.

A transmitter for use in the present invention must be able to insert a guard space in the transmitted data bursts and be able to adjust the duration of the guard space, so that it is just sufficient to eliminate signal degradation by delay spread. In addition, the transmitter may be adapted to receive a control signal, from a receiver, indicative of the amount of delay spread present in a received signal, and to use this signal to adjust the duration of the guard space, on a continuous basis. This ability to continuously vary the duration of the guard space, during system operation, is particularly valuable where the system is used in mobile telephony.

A receiver for use in the present invention must be able to adjust the reception window for OFDM bursts to match the size of the transmitted burst, as received. In particular, the FFT frame must be synchronised with the received OFDM burst, if the received signal is to be demultiplexed correctly. However, a receiver can still detect a received burst, even if its reception window is incorrectly set, and can adjust the reception window to match the correct value for the received signal. In addition, the receiver may measure the amount of delay spread present in the received signal and transmit a control signal, to the transmitter, causing the transmitter to adjust the duration of the guard space employed.

The present invention has particular application in mobile telephony, in which a plurality of base stations transmit data to a plurality of mobile stations. In such systems, delay spread may vary during the course of transmission, between a given base station and a given mobile, as the mobile's position continuously changes. Furthermore, in such systems, traffic capacity is at a premium. The ability to continuously measure the delay spread present and adjust guard spaces, in OFDM bursts, to ensure undegraded transmission with a minimum guard space duration, conserves traffic capacity in a transmission channel.

The design and implementation of OFDM systems are well known to those skilled in the art of telecommunications, and the manner in which an OFDM system, implementing the present invention, can be realised will be readily apparent to those skilled in the art, from the foregoing description.

CLAIMS

1. An OFDM system comprising a receiver and a transmitter, said transmitter being adapted to transmit data in OFDM symbol bursts in which, in the time domain, a portion of a symbol burst is repeated within said symbol burst as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised in that said repeated portion of a symbol burst has a duration which is variable and which is adjusted, during system operation, to a minimum duration necessary to prevent data loss caused by delay spread.

2. An OFDM system as claimed in claim 1, characterised in that said receiver is adapted to vary said time window to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

3. An OFDM system as claimed in either claim 1, or claim 2, characterised in that the portion of said symbol burst which is repeated is copied from a leading edge of said symbol burst.

4. An OFDM system as claimed in any previous claim characterised in that said repeated portion of said symbol burst is repeated at a trailing edge of said symbol burst.

5. An OFDM system as claimed in any previous claim, characterised in that said receiver includes performance measuring means for measuring received signal quality and reception window adjusting means for adjusting said time window duration.

6. An OFDM system as claimed in claim 5, characterised in that said receiver is adapted to transmit a signal to said transmitter indicative of a level of delay spread in a received signal, and said transmitter is adapted to adjust said guard space duration to a minimum value necessary to prevent data loss caused by delay spread.

7. An OFDM system as claimed in any previous claim, characterised in that said guard space can be adjusted to a duration of between 0.2μs and 50μs.

8. An OFDM system as claimed in any previous claim, characterised in that said receiver is adapted to detect a transmitted signal when said time window is incorrectly adjusted.

9. An OFDM system as claimed in any previous claim, characterised in that said system includes a plurality of mobile stations and a plurality of base stations, and is adapted to operate as a mobile telecommunications system.

10. A receiver, for use with an OFDM system including a transmitter adapted to transmit data in OFDM symbol bursts, in which, in the time domain, a portion of a symbol burst is repeated within said symbol burst as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised in that said repeated portion of a symbol burst has a duration which is variable and said receiver is adapted to vary said time window to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

11. A receiver as claimed in claim 10, characterised in that said receiver includes performance measuring means for measuring received signal quality and reception

window adjusting means for adjusting said time window duration in response to a signal from said performance measuring means.

12. A receiver as claimed in claim 11, characterised in that said receiver is adapted to transmit a signal to said transmitter indicative of a level of delay spread in a received signal, and said transmitter is adapted to adjust said guard space duration to a minimum value necessary to prevent data loss caused by delay spread.

13. A receiver as claimed in any of claims 10 to 12, characterised in that said guard space can be adjusted to a duration of between 0.2μs and 50μs.

14. A receiver as claimed in any of claims 10 to 13, characterised in that said receiver is adapted to detect a transmitted signal when said time window is incorrectly adjusted.

15. A receiver as claimed in any of claims 10 to 14, characterised in that said receiver is a mobile radio telephony transceiver adapted for use with a mobile telecommunications system.

16. A method of operating an OFDM system comprising a receiver and a transmitter, by transmitting data as a series of OFDM symbol bursts, each symbol burst, in the time domain, having a portion thereof repeated therein as a guard space, said receiver having a time window with which, after demultiplexing, said symbol burst must be aligned, characterised by the repeated portion of a symbol burst having a variable duration, and adjusting said variable duration to produce a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

17. A method as claimed in claim 16 characterised in that said receiver time window is adjusted to produce, on demultiplexing, a guard space of a minimum duration necessary to prevent data loss caused by delay spread.

18. A method as claimed in either claim 16, or claim 17, characterised by copying the repeated portion of said symbol burst from a leading edge thereof.

19. A method as claimed in any of claims 16 to 18, characterised by repeating the repeated portion of said symbol burst at a trailing edge of said symbol burst.

20. A method as claimed in any of claims 16 to 19, characterised by said receiver measuring received signal quality and adjusting said time window duration so that said received signal quality exceeds a predetermined threshold.

21. A method as claimed in any of claims 16 to 20, characterised in that said guard space can be adjusted to a duration of between 0.2μs and 50μs.

22. A method as claimed in any of claims 16 to 21, characterised by said receiver detecting a transmitted signal when said time window is incorrectly adjusted.

Fig. 1

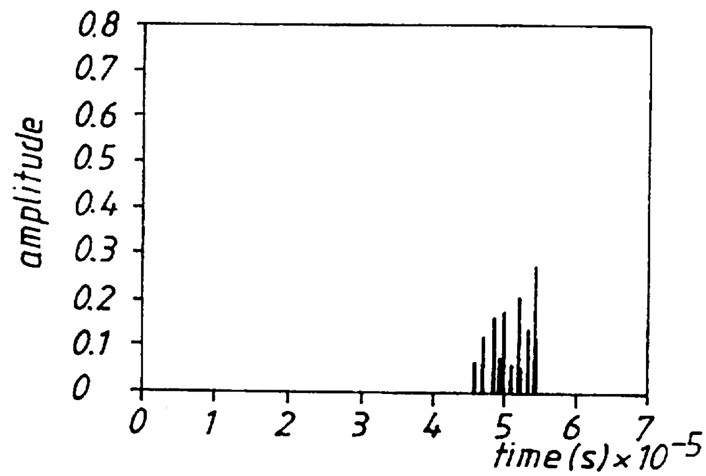


Fig. 2

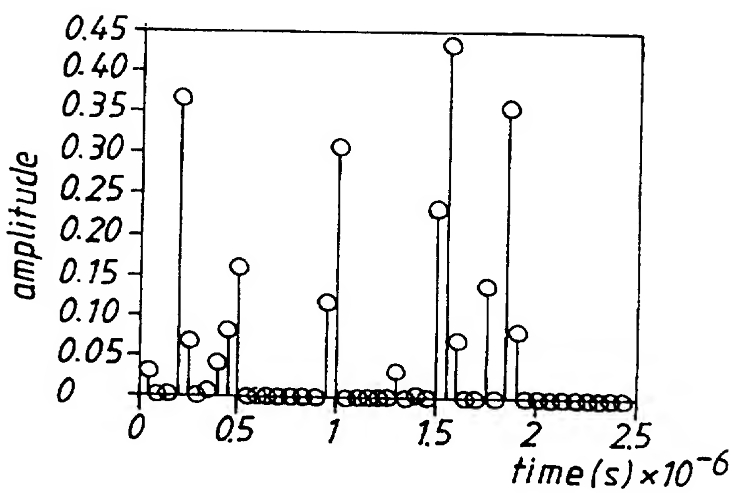


Fig. 3

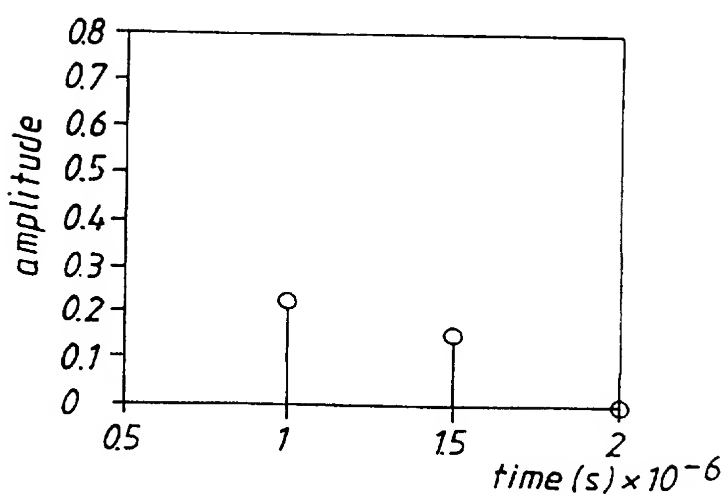
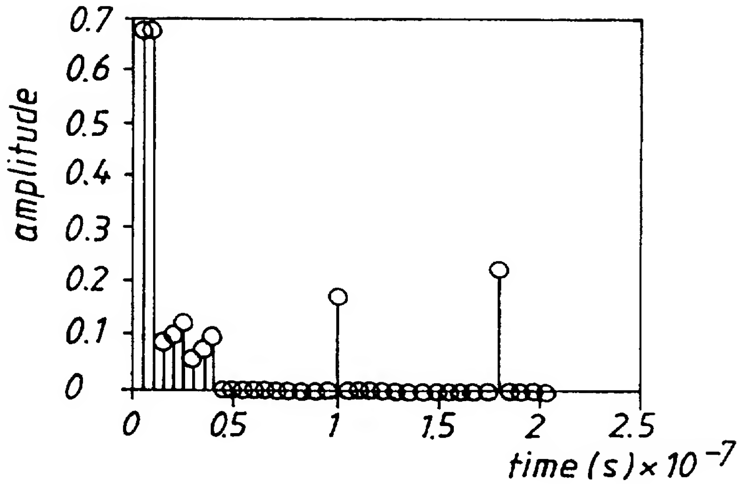


Fig. 4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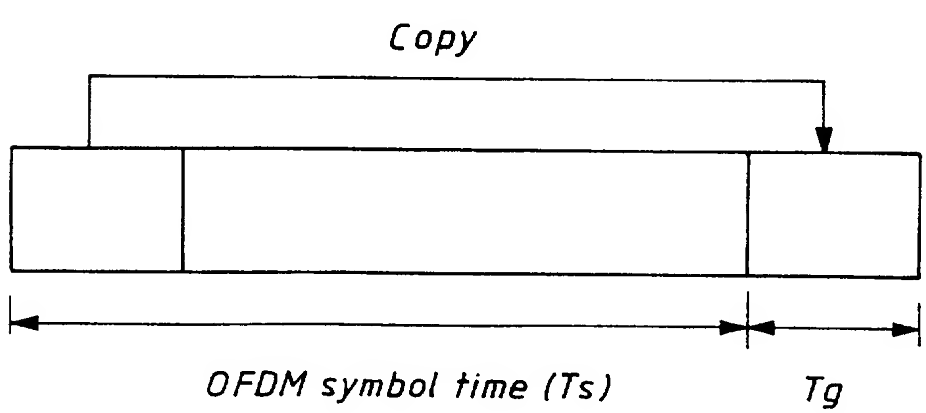
0.6
0.5
0.4
0.3
0.2
0.1
0
amplitude
0
0.5
1
1.5
2
2.5
time (s) × 10⁻⁷

Fig. 5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OFDM symbol time (Ts)
Tg

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00109

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 5/06
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 4425713 C1 (INSTITUT FüR RUNDFUNKTECHNIK GMBH), 20 April 1995 (20.04.95), claims 1-3, abstract --	1-22
A	WO 9406231 A1 (BRITISH BROADCASTING CORPORATION), 17 March 1994 (17.03.94), page 7, line 37 - page 8, line 9, abstract --	1-22
A	IEEE TRANSACTIONS ON BROADCASTING, Volume 41, No 1, March 1995, William Y. Zou et al, "COFDM: AN OVERVIEW", see especially abstract and chapter 3.3. -- --------	1-22

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☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

02/04/97

International application No.
PCT/SE 97/00109

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 4425713 C1	20/04/95	AU 3162795 A	16/02/96
		WO 9602989 A	01/02/96
WO 9406231 A1	17/03/94	AU 4975493 A	29/03/94
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		US 5610908 A	11/03/97